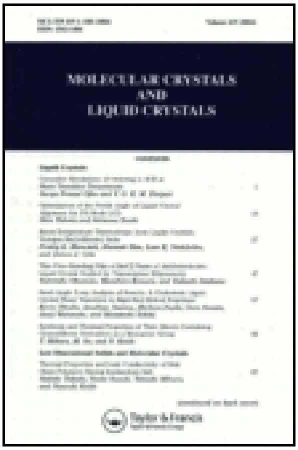

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Enhancement of the Luminance Efficiency of Blue Organic Light-Emitting Devices Fabricated Utilizing a Mixed Host Emitting Layer

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*The luminance efficiency of the blue organic light-emitting devices (OLEDs) with a mixed host emitting layer (EML) consisting of a 2-*t*-butyl-9,10-di-2-naphthylanthracene (TBADN) and 4,4′-Bis[4-(diphenylamino)styryl]biphenyl (BDAVBi)-doped 1,3-bis(carbazol-9-yl)benzene (mCP) layer at 20 mA/cm^2 was 5.78 cd/A, indicative of highly efficient OLEDs. Electroluminescence spectra for the OLEDs with a mixed host EML showed that a dominant peak at 467 nm corresponding to the BDAVBi doped mCP layer together with a shoulder at 491 nm related to the combination of the TBADN doped mCP layer and the BDAVBi doped mCP layer appeared.*

Keywords: blue emitting layer; fluorescence; luminance efficiency; mixed host emitting layer; organic light-emitting devices; phosphorescence

I. INTRODUCTION

Organic light-emitting devices (OLEDs) have emerged as promising candidates for potential applications in the fabrication of next-generation full-color flat-panel displays [1–5]. OLED displays have attracted much

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attention due to their use in promising full color displays, which offer unique advantages of low driving voltage, low power consumption, high contrast, wide viewing angle, low cost, and fast response [6,7]. Potential applications of highly-efficient blue OLEDs have driven extensive efforts to fabricate various kinds of OLEDs with unique structures [8]. However, blue OLEDs still have inherent problems of low efficiency, poor color purity, and short lifetime in comparison with other red or green OLEDs [9]. Blue OLEDs with various structures were studied for enhancing their efficiency and color purity [10–15]. Even though some works concerning the enhancement efficiency of green or white OLEDs fabricated utilizing a hole transport layer (HTL) with a multiple heterostructure or a doping layer have been performed to improve the balance of holes and electrons in an emitting layer (EML) [16–20], studies on highly-efficient blue OLEDs fabricated utilizing a mixed host EML with a fluorescence or a phosphorescence doped layer have not been reported yet because of the complicated device-fabrication process.

This paper reports the electrical and the optical properties of blue OLEDs fabricated with a mixed host EML with a fluorescence doped layer or a phosphorescence doped layer deposited by using organic molecular-beam deposition (OMBD). Current density-voltage, luminance-voltage, and luminance efficiency-current density measurements were performed to investigate the electrical properties and the luminance efficiency of the OLEDs fabricated utilizing a mixed host EML with a 1.3-Bis(carbazol-9-yl)benzene (mCP) layer doped with a 3-Tert-butyl-9,10-di(naphtha-2-yl)anthracene, a 4,4′-Bis[4-(diphenylamino)styryl]biphenyl (BDAVBi) fluorescence dopant or a bis(3,5-difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl)iridium III (FIrpic) phosphorescence dopant, respectively. Electroluminescence (EL) measurements were carried out to investigate the optical properties and the color stabilization of OLEDs with various kinds of structures. The Commission Internationale de l’Eclairage (CIE) chromaticity coordinates corresponding to the emission colors for OLEDs with various kinds of structures were investigated in order to clarify the blue color purity. The electrical and the optical properties of the OLEDs with a 8% FIrpic and a 5% TBADN doped mCP and a 5% BDAVBi and 5% 2-*t*-butyl-9,10-di-2-naphthylanthracene (TBADN) doped mCP mixed host EML were compared with those of OLEDs with a undoped EML or a doped conventional EML.

II. EXPERIMENTAL DETAILS

The sheet resistivity and the thickness of the indium-tin-oxide (ITO) thin films coated on glass substrates used in this study were

15 Ω/square and 100 nm, respectively. The ITO coated substrates were cleaned using ultrasonic treatment of acetone, methanol, then distilled water at 60°C for 15 min and were thoroughly rinsed in de-ionized water thoroughly. The chemically cleaned ITO substrates were kept for 48 h in isopropyl alcohol. After the chemically cleaned ITO substrates had been dried by using N_2 gas with a purity of 99.9999%, the surfaces of the ITO substrates were treated with an oxygen plasma for 2 min at an O_2 pressure of approximately 2×10^{-2} Torr. The five kinds of samples used in this study were deposited on ITO thin films coated on glass substrates by using OMBD with tungsten effusion cells and shutters at a chamber pressure of about 5×10^{-6} Torr. After organic and metal depositions, the OLED devices were encapsulated in a glove box with O_2 and H_2O concentrations below 1 ppm. A desiccant material consisting of a barium-oxide powder was used to absorb the residual moisture and oxygen in the encapsulated device. The deposition rates of the organic layers and the metal layers were approximately 0.1 and 0.15 nm/s, respectively, and the deposition rates were controlled by using a quartz crystal monitor. The size of the emitting region in the pixel was $3 \times 3\,\text{mm}^2$. The current density-voltage characteristics of the OLEDs were measured on a programmable electrometer with built-in current and voltage measurement units (model SMU-236, Keithely). The luminance and color coordinates were measured by using a chromameter CS-100A (Minolta), and the EL spectrum was measured by using a luminescence spectrometer LS50B (Perkin-Elmer).

III. RESULTS AND DISCUSSION

Figure 1 shows schematic diagrams of the fabricated blue OLEDs of devices (a) I, (b) II, (c) III, (d) IV, and (e) V. Devices I and II are the conventional blue OLEDs with an undoped mCP EML or an undoped TBADN EML. The blue OLED with the mixed host EML consisting of a 5% TBADN-doped mCP EML is shown in Figure 1(c), and the blue OLEDs with a phosphorescence mixed host EML consisting of a 8% FIrpic and 5% TBADN-doped mCP layer or the blue OLEDs with a fluorescence mixed host EML consisting of a 5% BDAVBi and 5% TBADN doped mCP layer are shown in Figures 1(d) and 1(e), respectively.

Figure 2 shows the current densities as functions of the applied voltage for the OLEDs of devices I, II, III, IV, and V. While the driving voltage of device II has the lowest value among the devices, that of device I has the highest value. Because the electron mobility of the fluorescent TBADN in device I is better than that of the mCP in device II, the electrons and holes are more balanced in the TBADN EML in

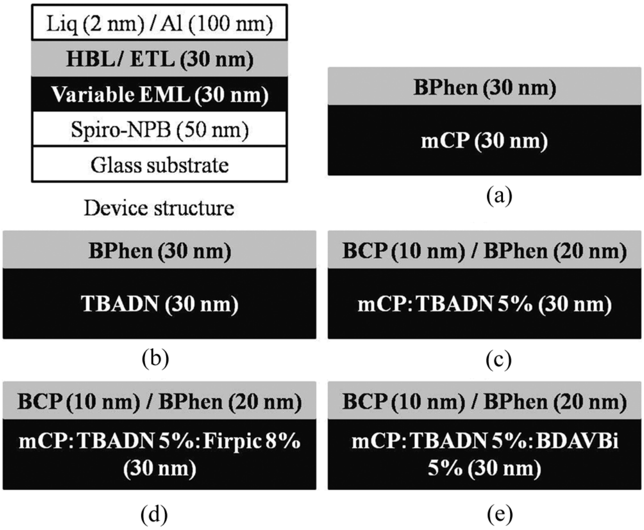

FIGURE 1 Schematic diagrams for the OLEDs of devices (a) I, (b) II, (c) III, (d) IV, and (e) V.

device II, resulting in a decrease in the driving voltage. The driving voltage of device III with the 5% TBADN-doped mCP EML is much lower than that of the device I because the TBADN molecules in the

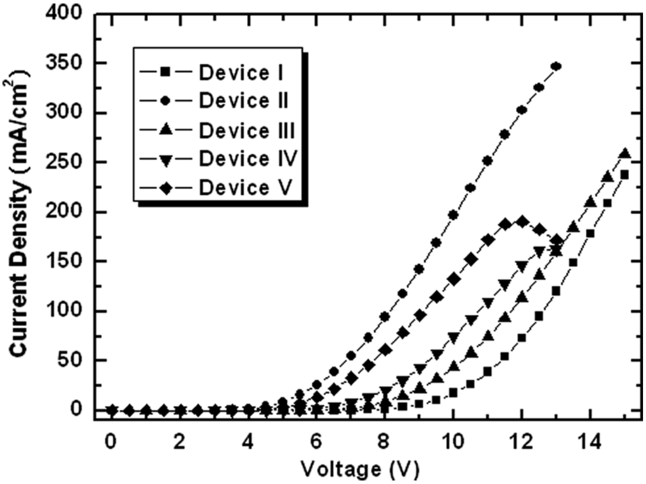

FIGURE 2 Current densities as functions of the applied voltage for OLEDs with various structures. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, IV, and V, respectively.

mCP of device III increase the electron mobility. Phosphorescence Firpic and fluorescence BDAVBi dopants in a 5% TBADN-doped mCP EML in devices IV and V decrease driving voltage due to an increase in the carrier mobility of the mixed host EML.

Figure 3 shows the luminances as functions of the applied voltage for devices I, II, III, IV, and V. While the luminance of device I with a mCP EML is the lowest value, the device IV with a 5% BDAVBi and 5% TBADN-doped mCP EML is the highest value. The maximum luminance of device V with a 5% TBADN and 5% BDAVBi-doped mCP EML is 6,750 cd/m^2, and the turn-on voltage of device V is below 5 V. The maximum luminance of device II with the TBADN EML is 3,681 cd/m^2, and the turn-on voltage of device II is similar to that of device V. The luminance of device IV with a 5% TBADN and 8% FIrpic-doped mCP EML is smaller than the other devices, of which the TBADN molecules may not transfer the exciton energy to the phosphorescence dopant.

Figure 4 shows the luminance efficiencies as functions of the current density for the OLEDs of devices I, II, III, IV, and V. The luminance efficiency of device V at 20 mA/cm^2 is 5.78 cd/A, which is the largest value among the other devices. Because EL spectra for devices I and III appear in the deep blue region, the luminance efficiencies of devices I and III are very small. The luminance efficiency of OLEDs with a fluorescence EML and a phosphorescence doped EML in the current

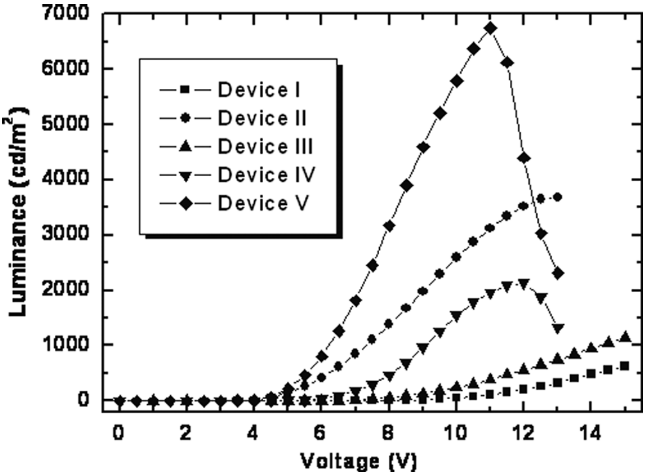

FIGURE 3 Luminance as functions of the applied voltage for OLEDs with various structures. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, IV, and V, respectively.

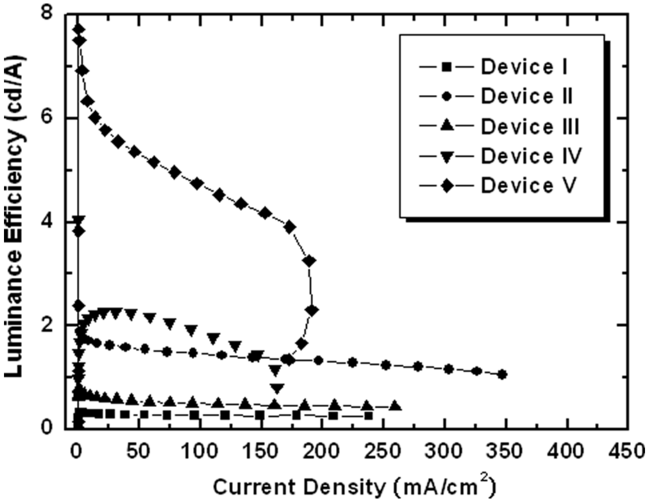

FIGURE 4 Luminance efficiencies as functions of the current density for OLEDs with various structures. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, IV, and V, respectively.

density region of about 200 mA/cm^2 is low. Because the device V with a 5% TBADN and 5% BDAVBi doped mCP EML is an effective energy transfer to fluorescence dopant, the primary stage of exciton

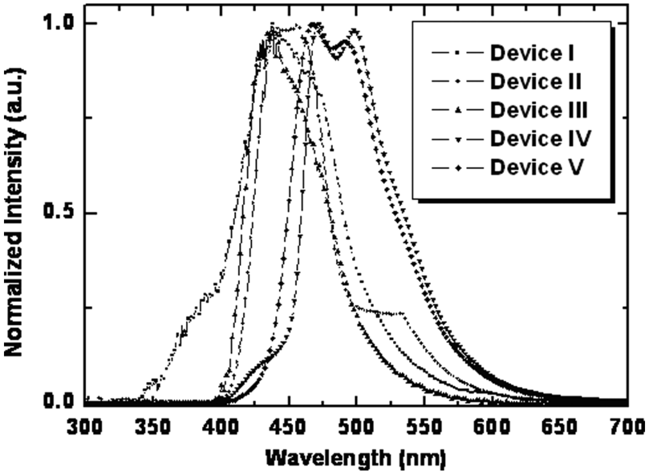

FIGURE 5 Electroluminescence spectra at 13 V for OLEDs with various structures. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, IV, and V, respectively.

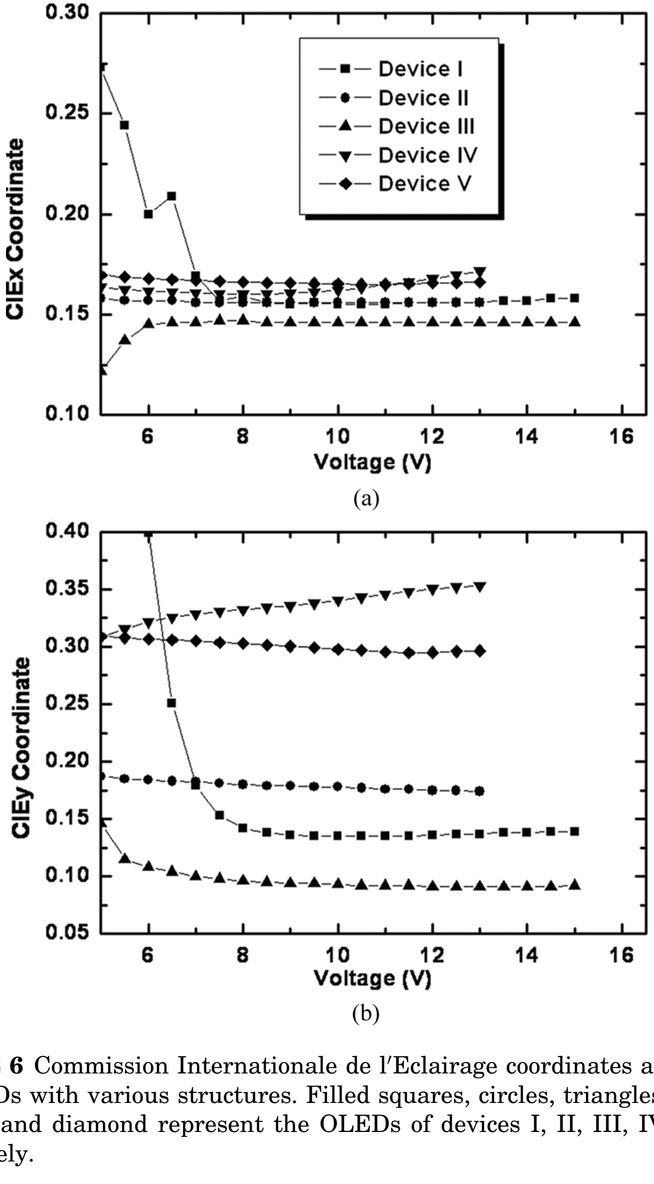

FIGURE 6 Commission Internationale de l′Eclairage coordinates at 10 V for the OLEDs with various structures. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, IV, and V, respectively.

generation occurs in the mCP molecules, and the formed excitons in the mCP molecules are transferred into the TBADN molecules and the BDAVBi molecules, resulting in an emission of the excitons due to their transition from excited states to ground state. Furthermore, the

TBADN molecules similar to the mCP molecules generate excitons, and the generated excitons are transferred into the BDAVBi fluorescence dopant and are decayed to the ground state. Therefore, the luminance efficiency of device V is a larger than those of other devices.

Figure 5 shows the EL spectra at 13 V for devices I, II, III, IV, and V. The dominant peaks of devices I, II, III, IV, and V appear at 438, 438, 437, 471, and 467 nm, respectively, and the corresponding FWHMs are 49, 56, 74, 75, and 79 nm, respectively. The dominant peaks of devices V shift to lower energy in comparison with those in devices I, II, and III. Because the phosphorescence and fluorescence dopants have small energy band gaps, the dominant peaks of the EL spectra for devices IV and V appear at blue color regions. Furthermore, the only dopant peak of the EL spectra for the device V with a 5% TBADN and 5% BDAVBi doped mCP EML appears.

Figure 6 shows CIE coordinates as functions of the applied voltage for the OLEDs of devices I, II, III, IV, and V. The CIE coordinates of device III are (0.14, 0.09), which are very close to the national television standard committee (NTSC) blue coordinates. While the CIE coordinates of devices II, III, and V are stable regardless of the variation of the applied voltage, the CIE coordinates of device IV shift far away from the NTSC blue coordinates with increasing applied voltage. The CIE coordinates of device V of a 5% TBADN and 5% BDAVBi doped mCP EML are very stable.

IV. SUMMARY AND CONCLUSIONS

The luminance efficiency of the OLEDs with a 5% TBADN and 5% BDAVBi doped mCP EML at 20 mA/cm^2 was 5.78 cd/A, indicative of the highest value of the luminance efficiency among devices. The EL spectra for OLEDs with a 5% TBADN and 5% BDAVBi doped mCP EML showed that a dominant peak appeared at 467 nm and that the shoulder peak related to a 5% TBADN and 5% BDAVBi doped mCP EML appeared at 491 nm. The CIE coordinates of the OLEDs with a 5% TBADN and 5% BDAVBi doped mCP EML at 13 V were (0.166, 0.296), indicative of a blue color. These results indicate that high efficiency blue OLEDs can be fabricated utilizing mixed host EML containing of a fluorescence doped layer.

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